Fermi National Accelerator Laboratory

Particle Correlations in p-p̄ Interactions at √s = 1800 and 630 Gev*

The CDF Collaboration

presented by

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Abstract. Preliminary results on Bose-Einstein correlations and two particle pseudorapidity correlations in p-p̄ interactions at $\sqrt{s}$ = 1800 and 630 GeV are presented. Data were collected with a "minimum-bias" trigger with the Collider Detector at Fermilab. The size of the particle emitting source, measured via Bose-Einstein interference at $\sqrt{s}$ =1800 GeV, is of the order of 1 fm. The observed short-range pseudorapidity correlations, compared to lower energy data, do not show any significant energy dependence.

Introduction

The study of correlations among secondary particles produced in p-p or p-p̄ collisions has been, for a long time, an important tool for the analysis of soft hadronic interactions. Despite the copious amount of data accumulated, so far covering an energy range from a few GeV to 900 GeV in the cms, the existing phenomenological models are not able to give an exhaustive explanation consistent with all the experimental results. Moreover, it appears very hard to obtain a coherent description of the data from the fundamental principles of QCD, given the difficulties of such a theory in the non

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perturbative regime.

So there is still strong need of experimental work and it is worthwhile to collect any new piece of information.
Here are presented some preliminary results on Bose-Einstein correlations and on two particle pseudorapidity correlations in p-p̄ interactions at $\sqrt{s}$=1800 and 630 GeV. The experiment is performed by the CDF Collaboration at the Fermilab Tevatron-Collider.

Detector and Data Selection

The experimental apparatus is described in detail elsewhere[1]. Here only a brief description of those parts of the detector which are relevant to the present analysis is reported. Two beam-beam counter scintillator hodoscopes (BBC), located upstream and downstream of the central detector and covering the pseudorapidity range $3.24 \leq \eta \leq 5.90$ are used for the trigger. The vertex time projection chamber (VTPC), surrounding the beam pipe in the central region and covering the pseudorapidity range $| \eta | \leq 3.5$, provides a measurement of the η of each track. A limited φ determination is provided; there is no information on charge and momentum. Just outside the VTPC the central tracking chamber (CTC), a large volume axial drift chamber with small angle stereo wire layers, measures all the kinematic parameters of the tracks, η, φ and p_t, with an excellent momentum resolution. It covers a range of pseudorapidity of ± 1.3 units around 0.

The events were collected with a "minimum bias" trigger which required at least one hit in both the BBC hodoscopes in coincidence with a beam crossing signal. Off-line cuts were applied, based on the vertex position given by the VTPC and on the BBC timing information, in order to reduce the non beam-beam interactions background [2]. Additional cuts requiring a minimum of 4 tracks in the VTPC in the interval $| \eta | < 3$ were applied. The acceptance of the trigger was estimated by Monte Carlo simulation from the total and elastic cross sections extrapolated from lower energy. At $\sqrt{s} = 1800$ GeV, with the above selection criteria, the trigger acceptance is about 96% for inelastic non-diffractive events, while it is low, about 16%, for single diffractive events.

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The final sample consists of 51,000 (4,800) mostly non diffractive events at $\sqrt{s}$ =1800 (630) GeV.

Bose-Einstein Correlations

Bose-Einstein correlations [3] arise from the interference of identical bosons emitted incoherently from different points of an extended source. The not distinguishable paths of the two identical bosons from the source to the detector, when its distance is very large compared to the source dimension, give rise to enhanced probability, relative to non identical particles, of finding them close together in phase-space.

In order to study this effect and following the Kopylov suggestion [4], the distribution, $I(q_t, q_0)$, of all pairs of identical particles originating from the same events, in the two variables:

$$\vec{q}_t = \frac{(\vec{P}_1 - \vec{P}_2) \times (\vec{P}_1 + \vec{P}_2)}{|\vec{P}_1 + \vec{P}_2|} \; ; \quad q_0 = |E_1 - E_2| \qquad (1)$$

is evaluated. This distribution is then compared to the same distribution, $I_0(q_t, q_0)$, of a reference sample. The ratio :

$$R(q_t, q_0) = I(q_t, q_0)/I_0(q_t, q_0) \qquad (2)$$

in presence of B-E interference shows an enhancement at small, typically below 200 MeV, values of q_t, q_0.

For this analysis CTC tracks were used. In order to ensure a good track selection with high efficiency only tracks with $p_t > 0.4$ GeV/c and $|\eta| < 1$ were accepted. After this selection the CTC track finding inefficiency is $\approx 1\%$. Preliminary results from Monte Carlo simulation indicate a good ($\approx 98\%$) CTC efficiency for pairs of tracks for all $q_t > 0.03$ GeV/c. A small contamination of duplicated tracks, in the like charged pairs sample, is observed at $q_t < 0.03$ GeV/c. In the final sample only events with at least three tracks in the above phase-space region were kept. All tracks were assumed to be pions. As a reference sample either the pairs of unlike charged particles from the same events, or pairs made combining tracks from different events were used. Figure 1 shows

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$\sqrt{s}$ GeV	q_0 MeV	γ	δ	β GeV^{-2}	α	r fm
1800 CDF	<100	0.90 ±0.02	0.10 ±0.02	25.1 ±4.7	0.56 ±0.07	0.99 ±0.09
63 PP	<200	0.91 ±0.02	0.03 ±0.04	30.9 ±3.2	0.67 ±0.03	1.13 ±0.04
63 $\bar{P}P$	<200	0.92 ±0.03	-0.02 ±0.06	28.3 ±5.0	0.43 ±0.05	1.03 ±0.07
630 UA1	<200		0 fixed		0.25 ±0.01	0.90 ±0.03

Table .1: Fit results for form (3) to the ratio $R(q_t)$ for CDF data (fig.1) and for data at 62 GeV [5] and 630 GeV [6].

the ratio R of like sign pairs to opposite sign pairs as a function of q_t for $q_0 < 100$ Mev. The rise of R for $q_t < 0.200$ GeV indicates the presence of B-E interference. The errors in fig. 1 are statistical only. Corrections for contamination of non pion tracks, particle decays, photon conversion and secondary interactions are not applied. The data of fig.1 were fitted to the form:

$$R(q_t) = \gamma(1 + \delta q_t)(1 + \alpha e^{-\beta q_t^2}) \qquad (3)$$

In order to avoid the problems with duplicated tracks at very small q_t, the fit has been restricted to the range $0.04 < q_t < 2$ GeV/c. The parametrization (3) is based on the assumption of a gaussian shape of the source spacial distribution. The size of the source is related to β through $r = \hbar c \sqrt{\beta}$. The parameter α is often referred to as the "incoherence parameter"; it is 1 for a completely incoherent source and 0 for a completely coherent one. It can be observed that any contamination of non identical pions in the analysed sample decreases the value of α. The parameter γ is a normalization factor and δ allows for the small variation of R at large q_t. In table 1 are summarized the results of the fit together with results from other experiments at different energies [5],[6]. The comparison of the data of table 1 shows a general agreement in the values of the fitted parameters.

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In particular, the size of the source r, which was already observed to be independent of energy up to $\sqrt{s} = 900$ GeV [6]*, is of the order of 1 fm also at $\sqrt{s} = 1800$ GeV.

The parametrization (3) is not unique, the form:

$$R(q_t) = \gamma(1 + 4\alpha J_1^2(\beta q_t)/(\beta q_t)^2)(1 + \delta q_t) \qquad (4)$$

is often used and fits the data as well as the form (3) with larger r. This has been checked with the present data obtaining a value of r about two time larger than that of table 1. Again this is in agreement with previous results.

Two Particle Pseudorapidity Correlations

The tendency of pairs of particles of a multiparticle final state, from a soft hadronic interaction, to be emitted within a rapidity range of about 1 or 2 units from each other has been observed over a wide range of cm energies [9,10]. For this analysis charged tracks measured by the VTPC in the range $|\eta| < 3$ at $\sqrt{s} = 1800$ and 630 GeV were used. The inclusive two particle correlation function is defined by:

$$C(\eta_1, \eta_2) = \rho''(\eta_1, \eta_2) - \rho'(\eta_1)\rho'(\eta_2) \qquad (5)$$

where:

$$\rho'(\eta) = \frac{1}{\sigma}\frac{d\sigma}{d\eta} = \frac{1}{N}\frac{\Delta n}{\Delta \eta}$$

$$\rho''(\eta_1, \eta_2) = \frac{1}{\sigma}\frac{d^2\sigma}{d\eta_1 d\eta_2} = \frac{1}{N}\frac{\Delta n_{12}}{\Delta \eta_1 \Delta \eta_2}$$

are the single and two particle pseudorapidity densities, Δn is the number of tracks in $\Delta \eta$; Δn_{12} is the number of pairs in $\Delta \eta_1$ and $\Delta \eta_2$ and N is the number of events.

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* The source size r does not depend on the cm energy, but depends on the event multiplicity [5,6,7]. This dependence seems not to be present at low energy, below ISR energies [8]. Due to the limited statistics of the present data sample, there has been no attempt to determine the dependence of r on multiplicity in our data.

Function (5) is constant if the joint production of pairs of particles does not differ from the independent production of two particles with the same pseudorapidity values. In the same way the semi-inclusive correlation function can be defined:

$$C_m(\eta_1, \eta_2) = \rho_m''(\eta_1, \eta_2) - \rho_m'(\eta_1)\rho_m'(\eta_2) \qquad (6)$$

In this case all the quantities are referred to a fixed charged multiplicity m. For this analysis only tracks in the interval $\mid \eta \mid < 3$ have been used and the event sample is restricted to the events with at least 6 tracks in the above range.

For that region the VTPC track reconstruction efficiency is greater than 95%. The data presented here are preliminary and not efficiency corrected. In addition other corrections have not yet been applied: i) tracks with $p_t < 50$ MeV/c do not traverse the full radius of the VTPC and spiral around the beam direction, resulting approximately in a 5% inefficiency; ii) contamination of tracks passing the selection cuts, extimated to be below 10%, comes from particle decays, photon conversion and secondary interactions. The figures 2a and 2b show the inclusive correlation function at 1800 and 630 GeV respectively. In these plots the function $C(\eta_1, \eta_2)$ is reported as a function of η_1 at various, fixed values of η_2.

Some general features, known from lower energy data, can be observed [9,10]: i) the function $C(\eta_1, \eta_2)$ has a peak at $\eta_1 \cong \eta_2$. This shows the tendency of the particles to be emitted in clusters in pseudorapidity space. ii) The height and the width of the correlation function at 1800 GeV are larger than at 630 GeV. This is related to the known property of the integral of $C(\eta_1, \eta_2)$ over the η_1, η_2 space which is connected to the second moment of the charged particle multiplicity distribution [10]. iii) The height of the peak remains constant, within errors, when varing η_2. This means that the correlation strength is almost independent of η.

The semi-inclusive correlation functions, at $\sqrt{s} = 1800$ GeV, computed in fixed multiplicity intervals, are shown in figure 3 at $\eta_2 = 0$ as a function of η_1.

Comparison with data at $\sqrt{s} = 900$ GeV [10] shows quite similar behaviour. In particular an increase of the height of the correlation peak is observed with increasing multiplicity. This is better seen

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in fig. 4 where the height of the correlation function (obtained averaging for each multiplicity bin the peak value of $C_m(\eta_1, \eta_2)$ over the range $\mid \eta \mid < 1.5$) is plotted as a function of the mean multiplicity in the bin.

The same data are shown in fig.5 as a function of the KNO variable $Z = m/ < m >$ together with data at lower energies. This figure shows that, within errors, there is no significant energy dependence of the semi-inclusive two particle correlation function.

Conclusions

Some analyses of particle correlations in soft proton-antiproton interactions are under study in minimum bias CDF data. Preliminary results, based on data from the 1987 run, indicate:

- Bose-Einstein interference between identical pions is observed. The measured radius of the particle emitting source, in agreement with previous results, is of the order of 1 fm and is independent of the cm energy.

- Two particle pseudorapidity correlations are also observed at $\sqrt{s} = 1800$ GeV and compared with data at 630 GeV. The inclusive correlation function shows, at the new energy, the same features observed at lower energies. The intensity of the semi-inclusive two particle correlation, at $\sqrt{s} = 1800$ GeV, increases with increasing multiplicity. The comparison with UA5 results shows no significant dependence on the cm energy.

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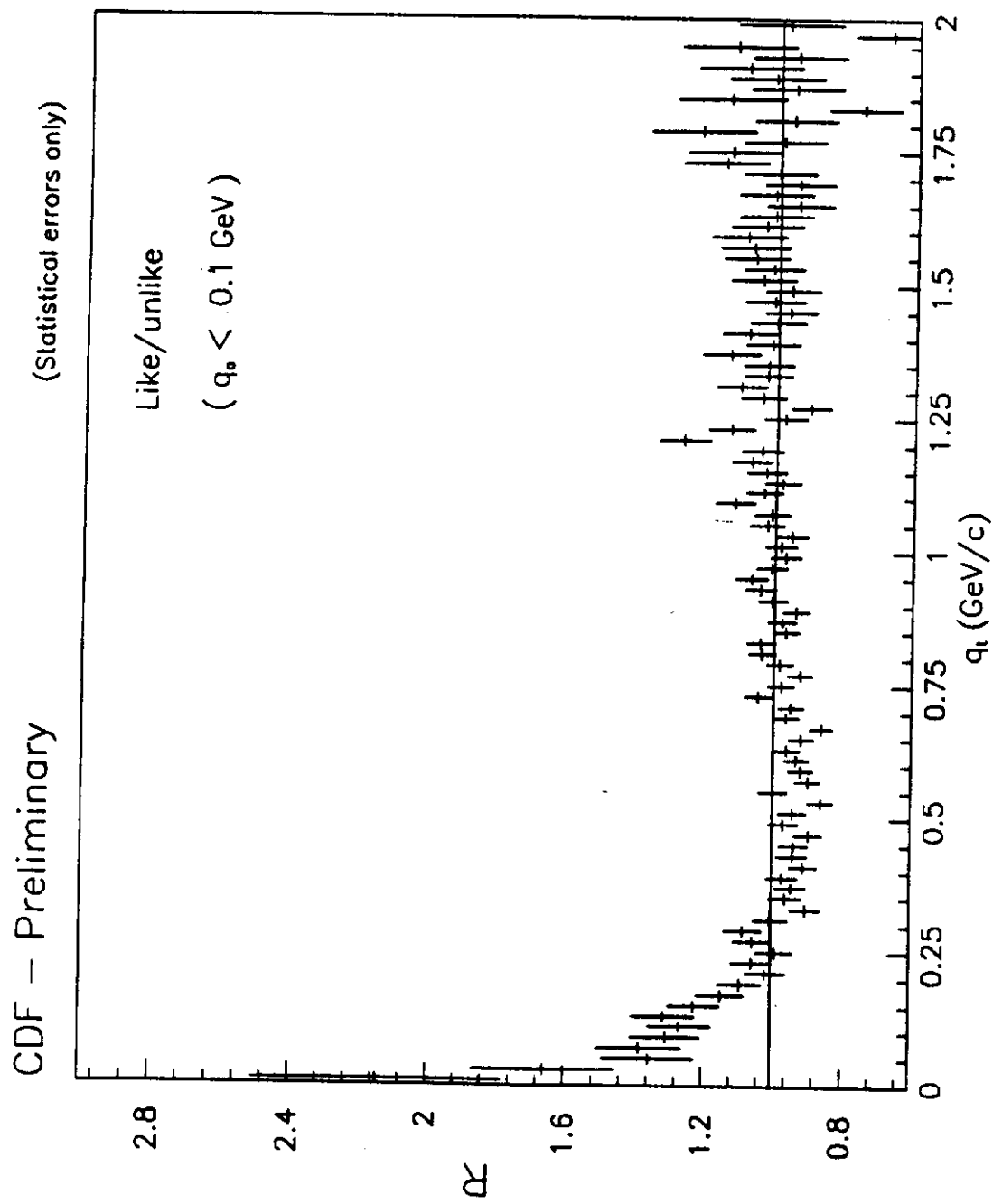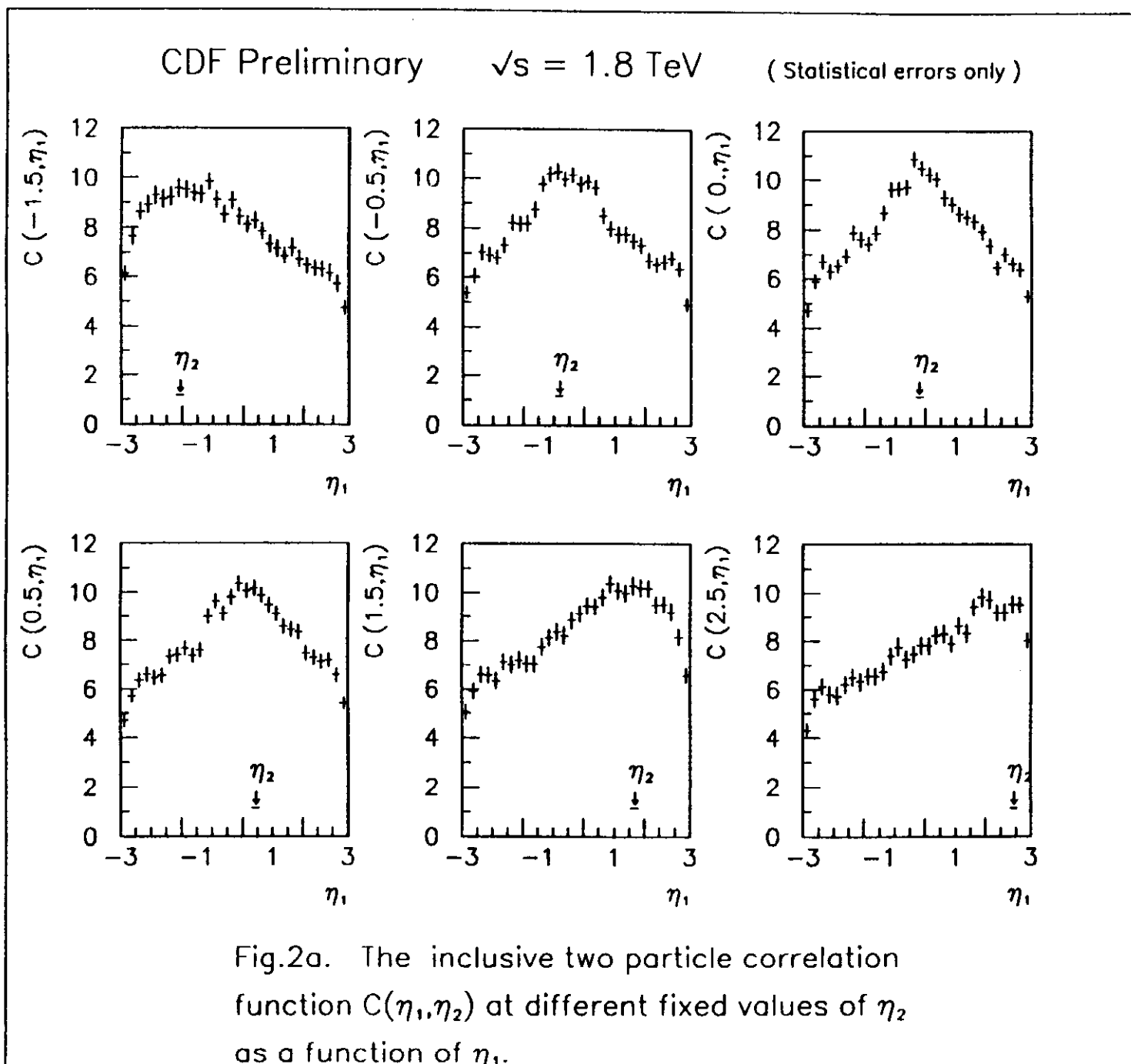[10] R.E.Ansorge et al., UA5 Collaboration: Z.Phys. C37 (1988) 37; and references therein.

CDF – Preliminary

(Statistical errors only)

Like/unlike

($q_0 <$ .0.1 GeV)

R

q_t (GeV/c)

Fig.1. The ratio $R(q_t)$ of like sign pairs to unlike sign pairs as a function of q_t for $q_0 < 100$ MeV at $\sqrt{s} = 1800$.

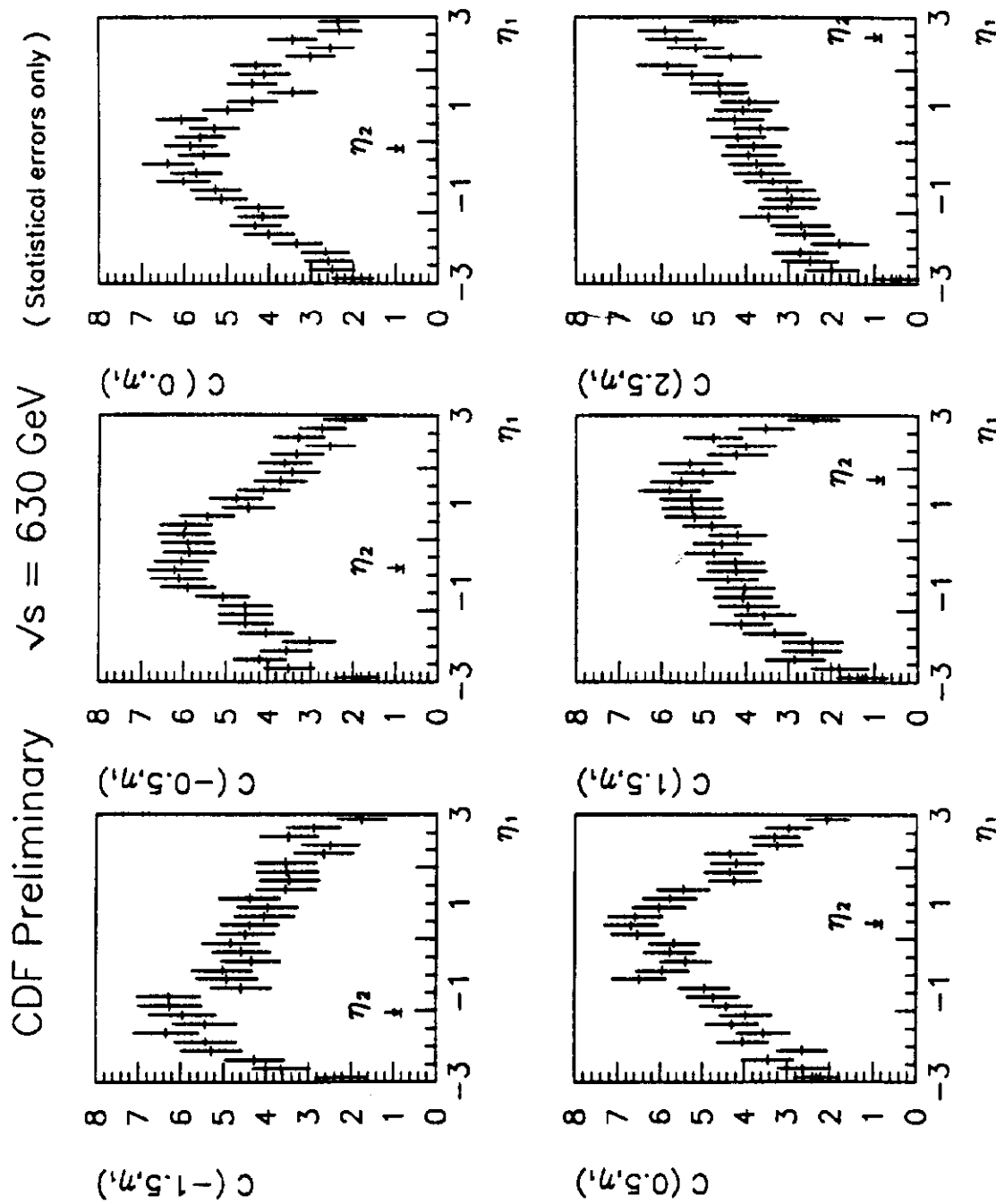CDF Preliminary   √s = 1.8 TeV   (Statistical errors only)

Fig.2a. The inclusive two particle correlation function $C(\eta_1,\eta_2)$ at different fixed values of η_2 as a function of η_1.

CDF Preliminary   √s = 630 GeV

(Statistical errors only)

η_2

η_2

η_2

η_2

η_2

η_2

$C(-1.5, \eta_1)$

$C(-0.5, \eta_1)$

$C(0.0, \eta_1)$

$C(0.5, \eta_1)$

$C(1.5, \eta_1)$

$C(2.5, \eta_1)$

η_1

Fig.2b. The inclusive two particle correlation function $C(\eta_1, \eta_2)$ at different fixed values of η_2 as a function of η_1.
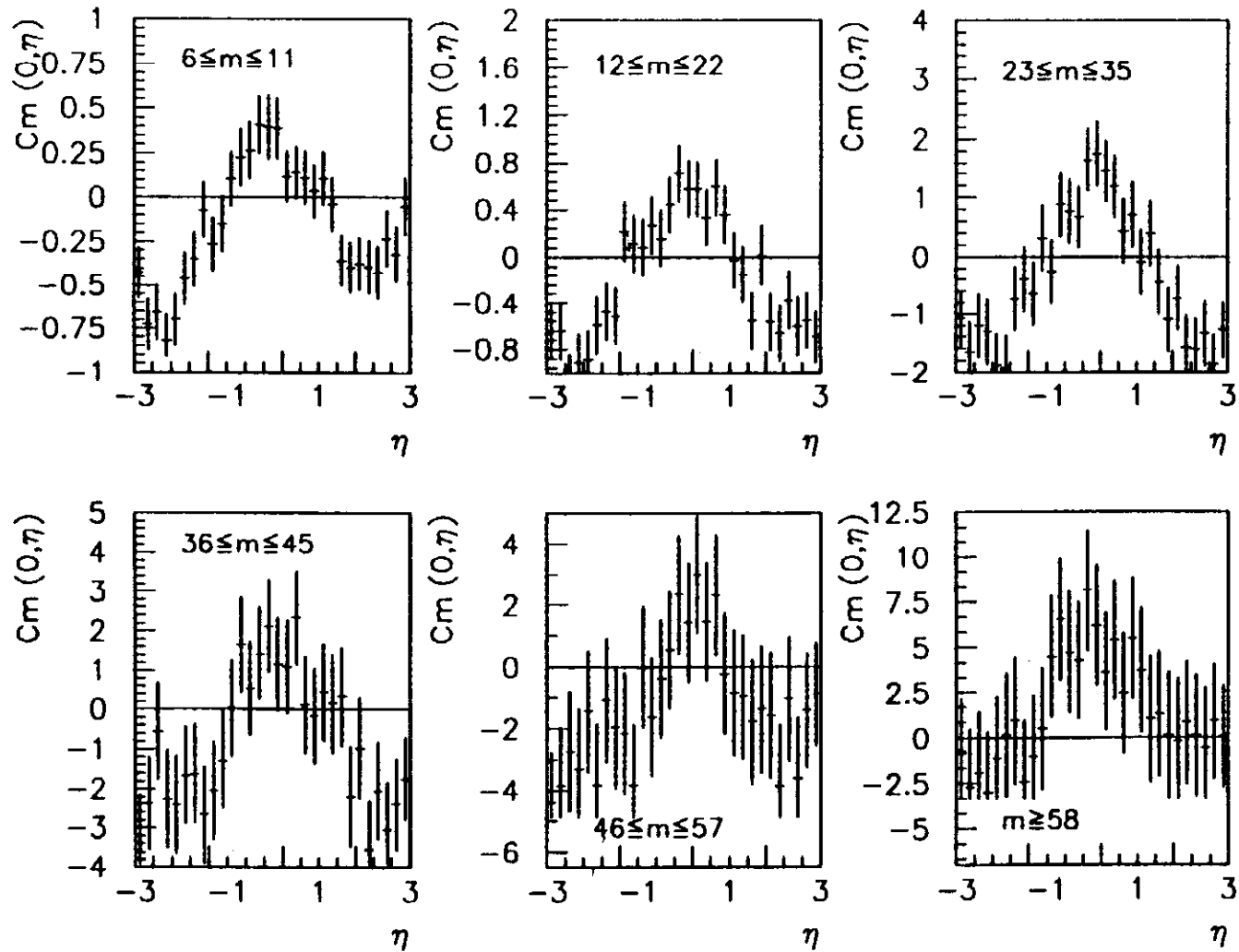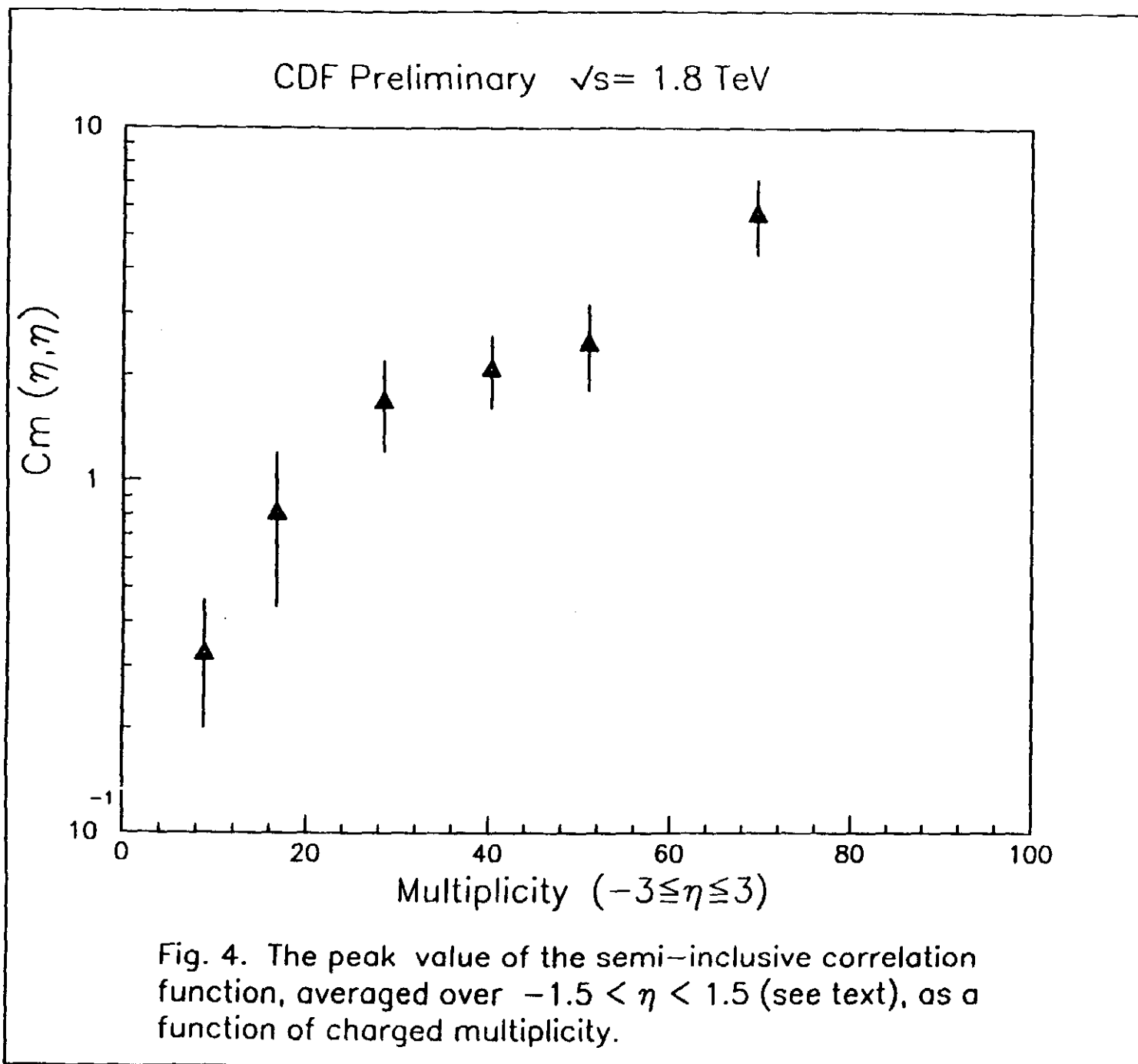
Fig. 3.   The   semi−inclusive   correlation function, $C_m(\eta_1,\eta_2)$, at $\eta_2=0$ as a function of η_1 for six multiplicity intervals. (m=multiplicity in $|\eta| < 3$).

Fig. 4. The peak value of the semi—inclusive correlation function, averaged over $-1.5 < \eta < 1.5$ (see text), as a function of charged multiplicity.
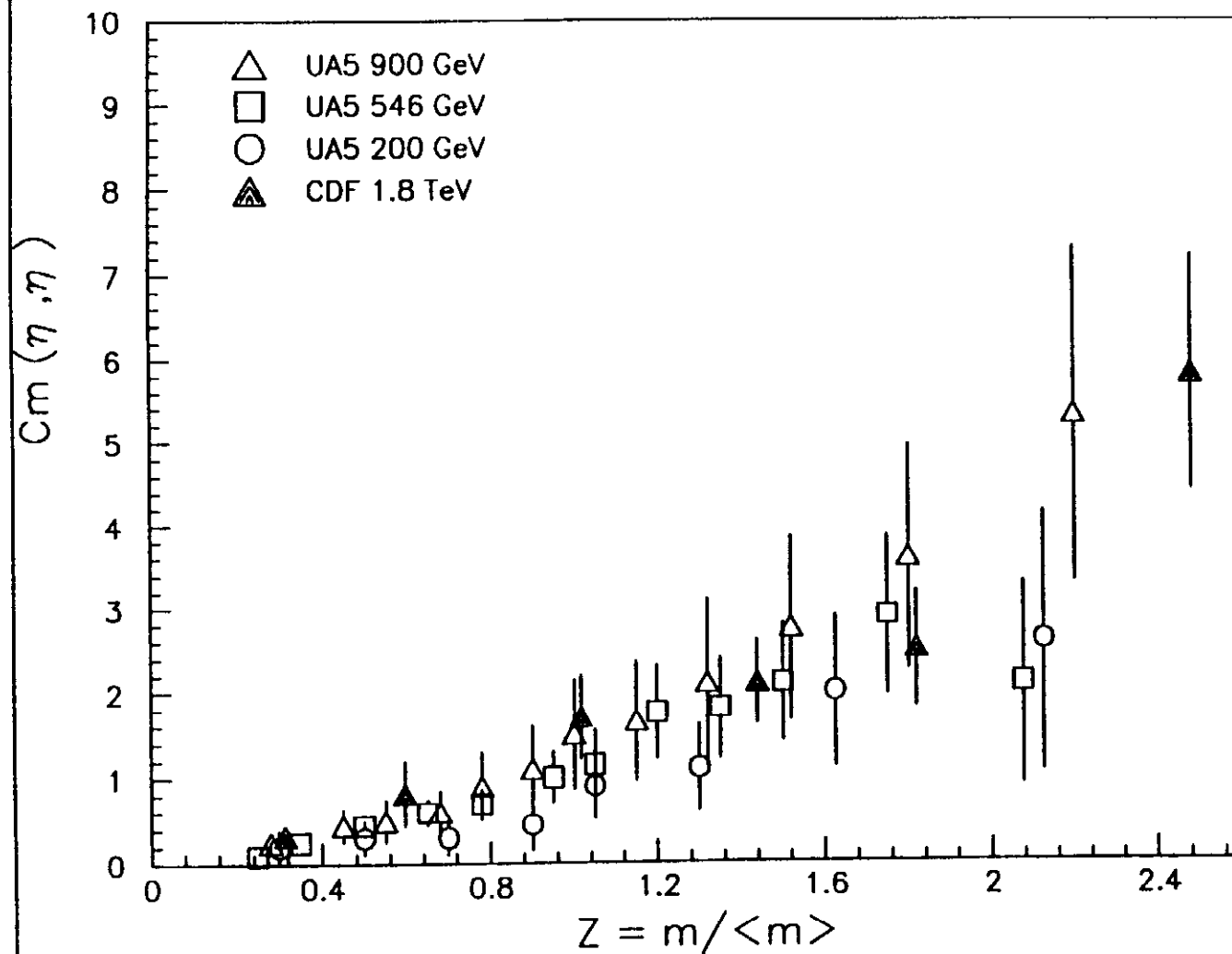
Fig. 5. The same data as in fig. 4 versus $Z = m/\langle m \rangle$ compared with data at 200, 546 and 900 GeV from ref.[10].